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(54) Process for Manufacturing Seamless Metal Tubes

(57) In the manufacture of seamless metal tubes by a cross-roll helical rolling process, or by a press piercing process, shells being worked are subjected to outside-diameter reduction by means of a mill having three or four rolls, without the use of internal sizing tools or a mandrel, so that the wall eccentricity is significantly improved.

FIG.1

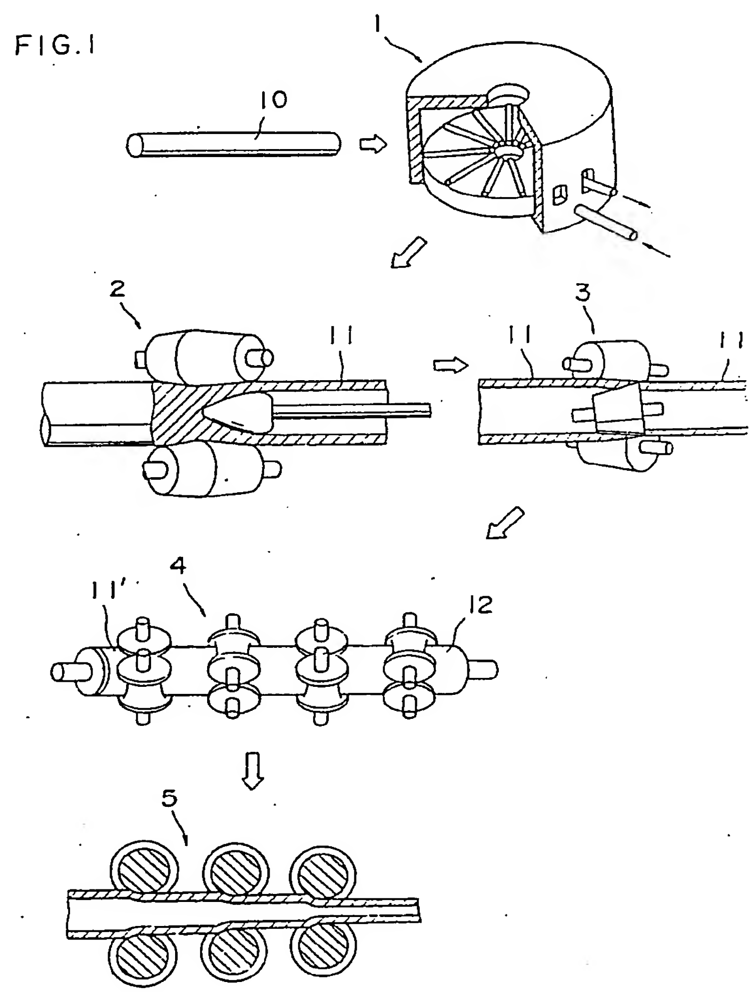

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FIG.1

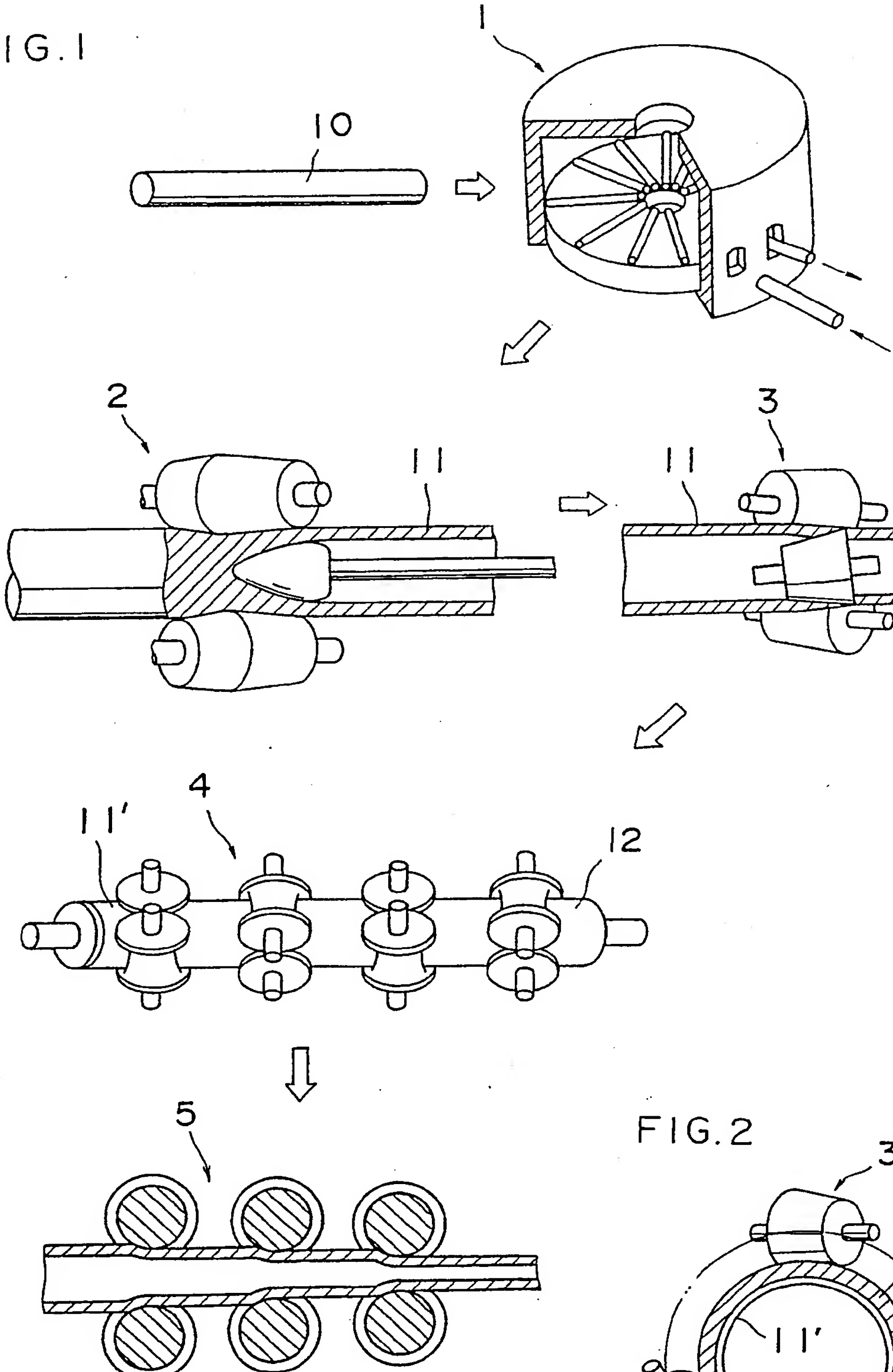

FIG.2

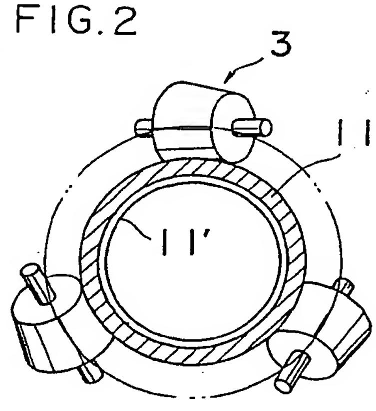

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FIG.3

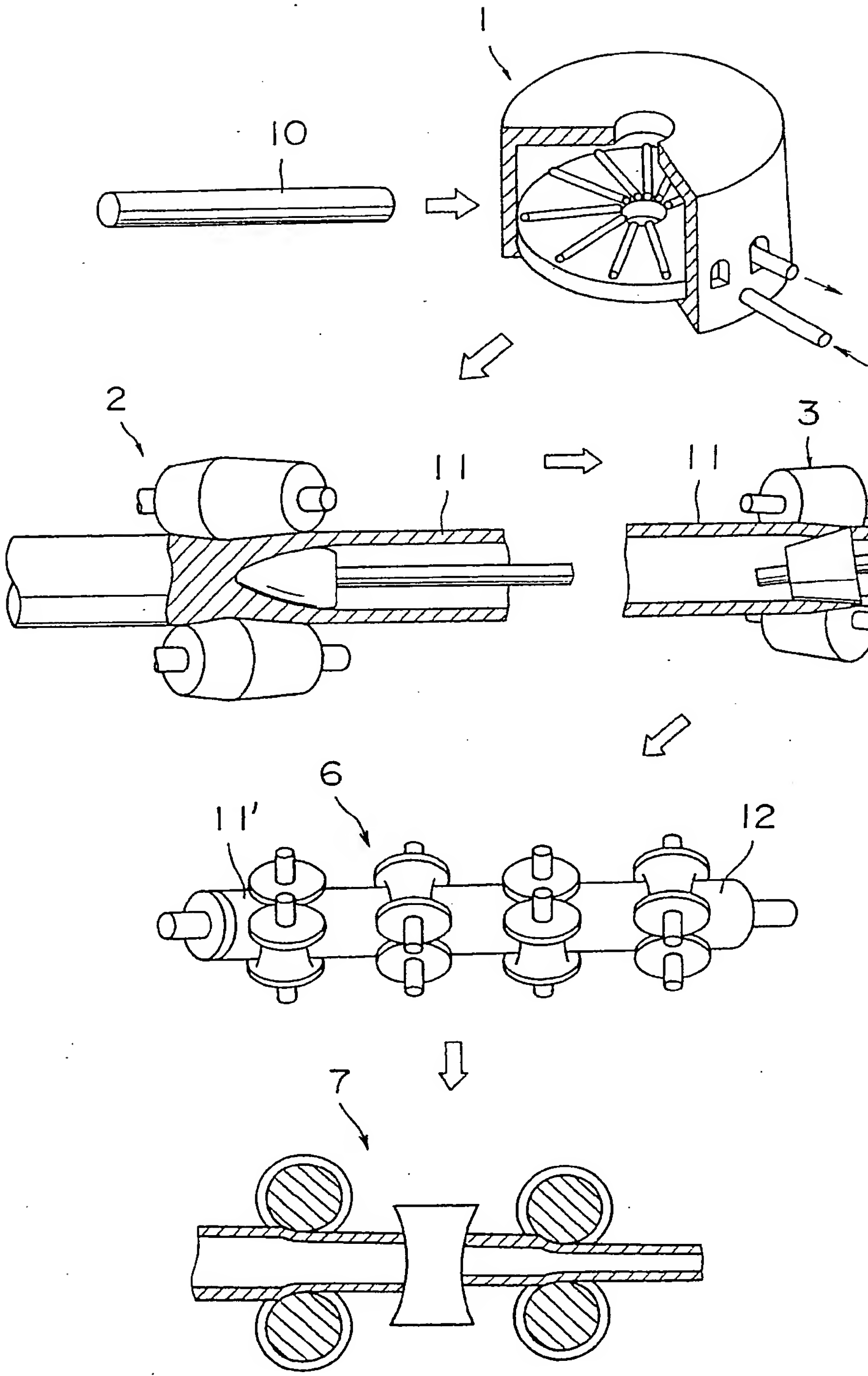


FIG. 4a

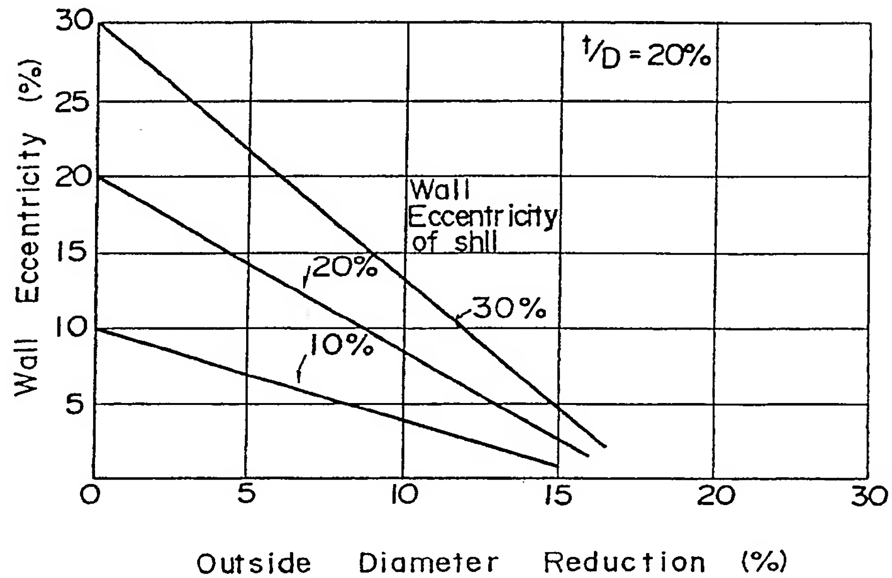

t/D = 20%
Wall Eccentricity (%)
30
25
20
15
10
5
Wall Eccentricity of shll
20%
30%
10%
0
5
10
15
20
30
Outside Diameter Reduction (%)

FIG. 4b

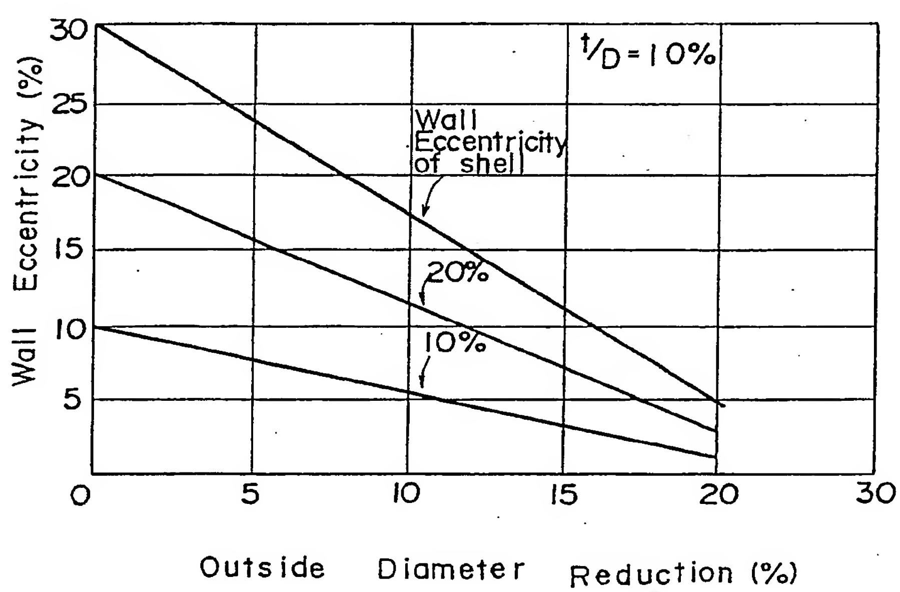

t/D = 10%
Wall Eccentricity (%)
30
25
20
15
10
5
Wall Eccentricity of shell
20%
10%
0
5
10
15
20
30
Outside Diameter Reduction (%)

FIG. 5a

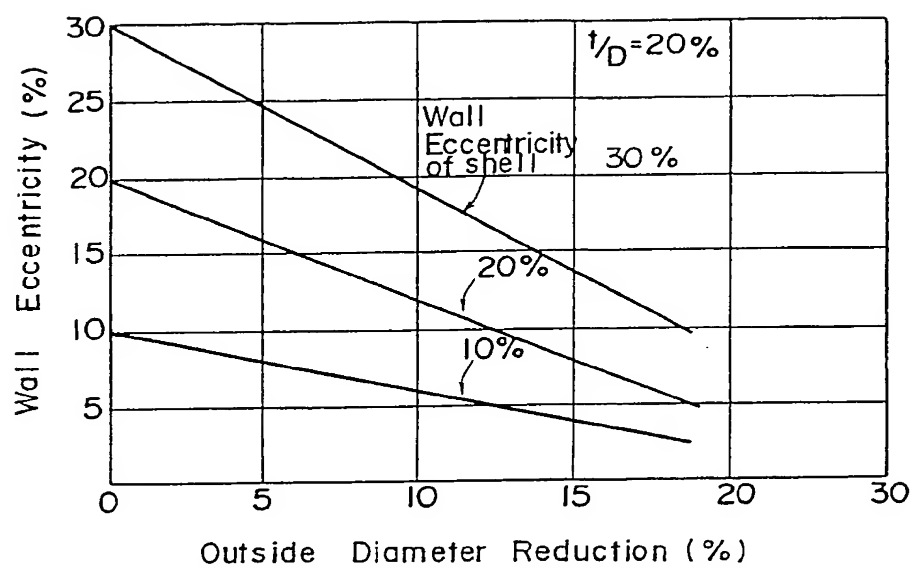

t/D=20%
Wall
Eccentricity
of shell
30%
20%
10%
Wall Eccentricity (%)
30
25
20
15
10
5
0
5
10
15
20
30
Outside Diameter Reduction (%)

FIG. 5b

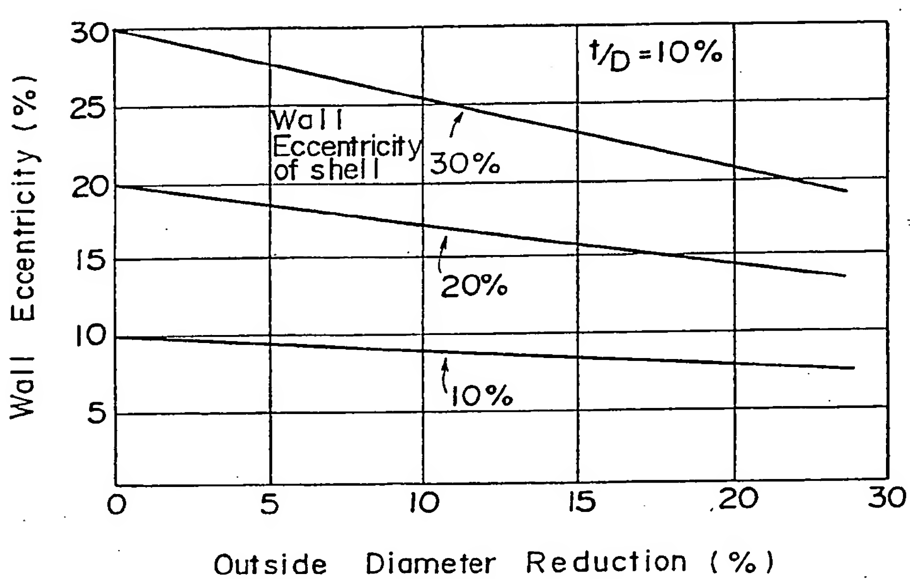

t/D=10%
Wall
Eccentricity
of shell
30%
20%
10%
Wall Eccentricity (%)
30
25
20
15
10
5
0
5
10
15
20
30
Outside Diameter Reduction (%)

FIG.6

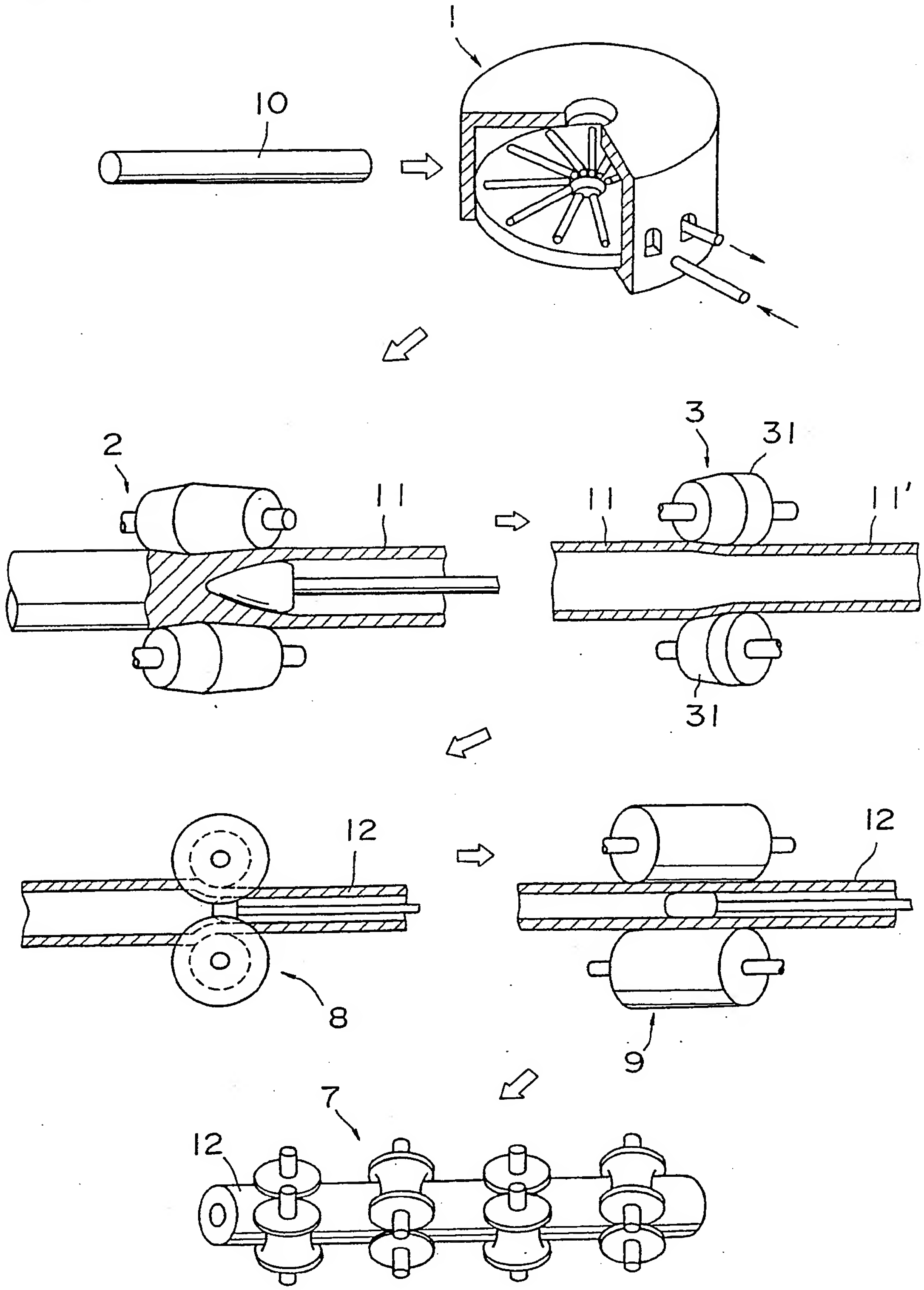


FIG. 7a

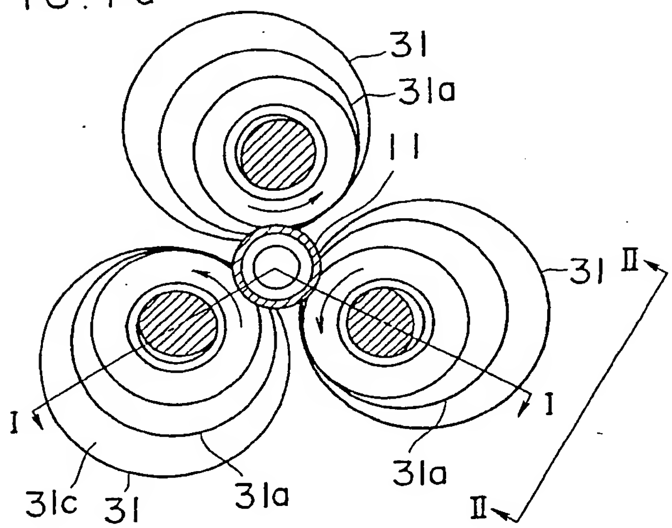


FIG. 7b

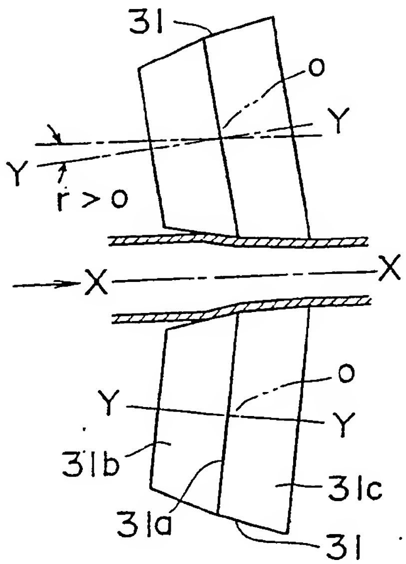


FIG. 7c

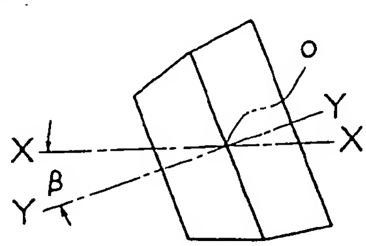


FIG. 8a

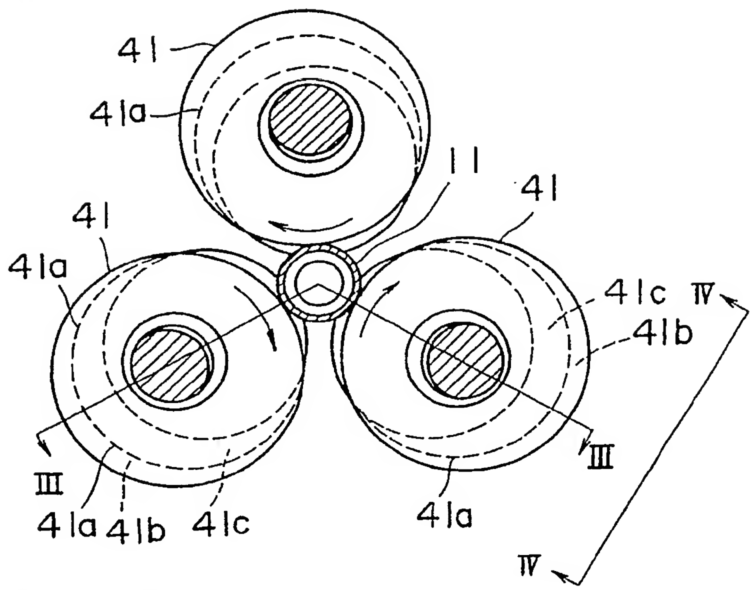


FIG. 8b

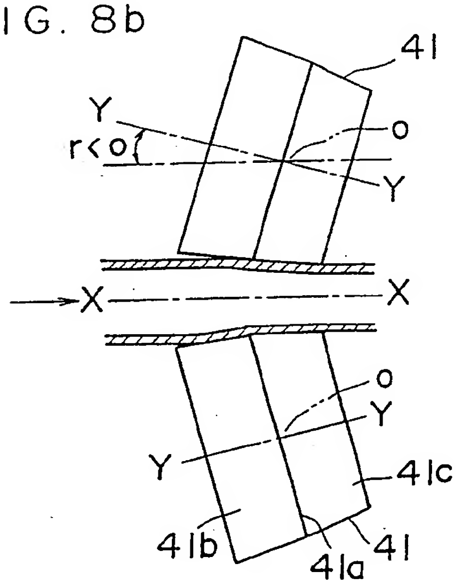


FIG.8c

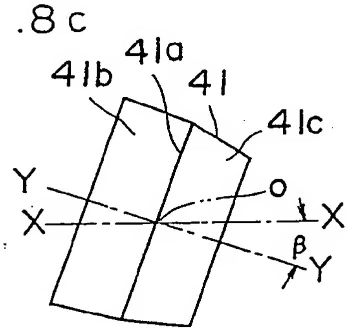


FIG. 9

Feed Angle 12°

t/D	Cross Angle (γ)					
	+4°	+2°	0°	−2°	−4°	−6°
14 %	⬠	⬠	○	○	○	○
12 %	⬠	⬠	⬠	○	○	○
10 %	⬠	⬠	⬠	⬠	○	○
8 %	⬠	⬠	⬠	⬠	⬠	○
6 %	⬠	⬠	⬠	⬠	⬠	⬠
4 %	⬠	⬠	⬠	⬠	⬠	⬠

FIG. 10

Feed Angle 8°

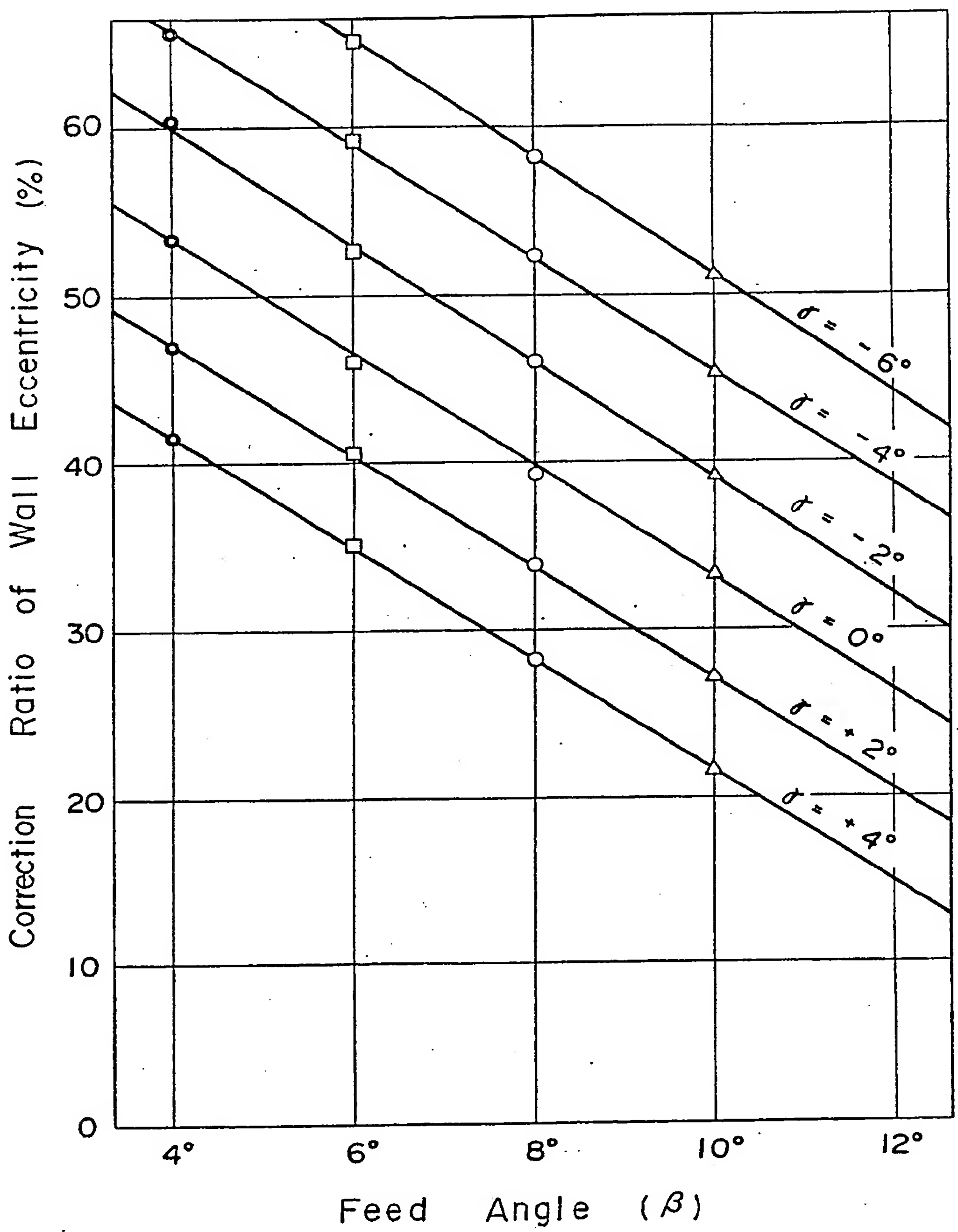
t/D	Cross Angle (γ)					
	+4°	+2°	0°	−2°	−4°	−6°
14 %	○	○	○	○	○	○
12 %	⬠	⬠	○	○	○	○
10 %	⬠	⬠	⬠	○	○	○
8 %	⬠	⬠	⬠	⬠	○	○
6 %	⬠	⬠	⬠	⬠	⬠	○
4 %	⬠	⬠	⬠	⬠	⬠	⬠

FIG. 11

Feed Angle 4°

t/D	Cross Angle (γ)					
	+4°	+2°	0°	−2°	−4°	−6°
14 %	○	○	○	○	○	○
12 %	○	○	○	○	○	○
10 %	⬠	⬠	○	○	○	○
8 %	⬠	⬠	⬠	○	○	○
6 %	⬠	⬠	⬠	⬠	○	○
4 %	⬠	⬠	⬠	⬠	⬠	○

FIG. 12



Correction Ratio of Wall Eccentricity (%)
0
10
20
30
40
50
60
4°
6°
8°
10°
12°
Feed Angle (β)
γ = -6°
γ = -4°
γ = -2°
γ = 0°
γ = +2°
γ = +4°

FIG.13

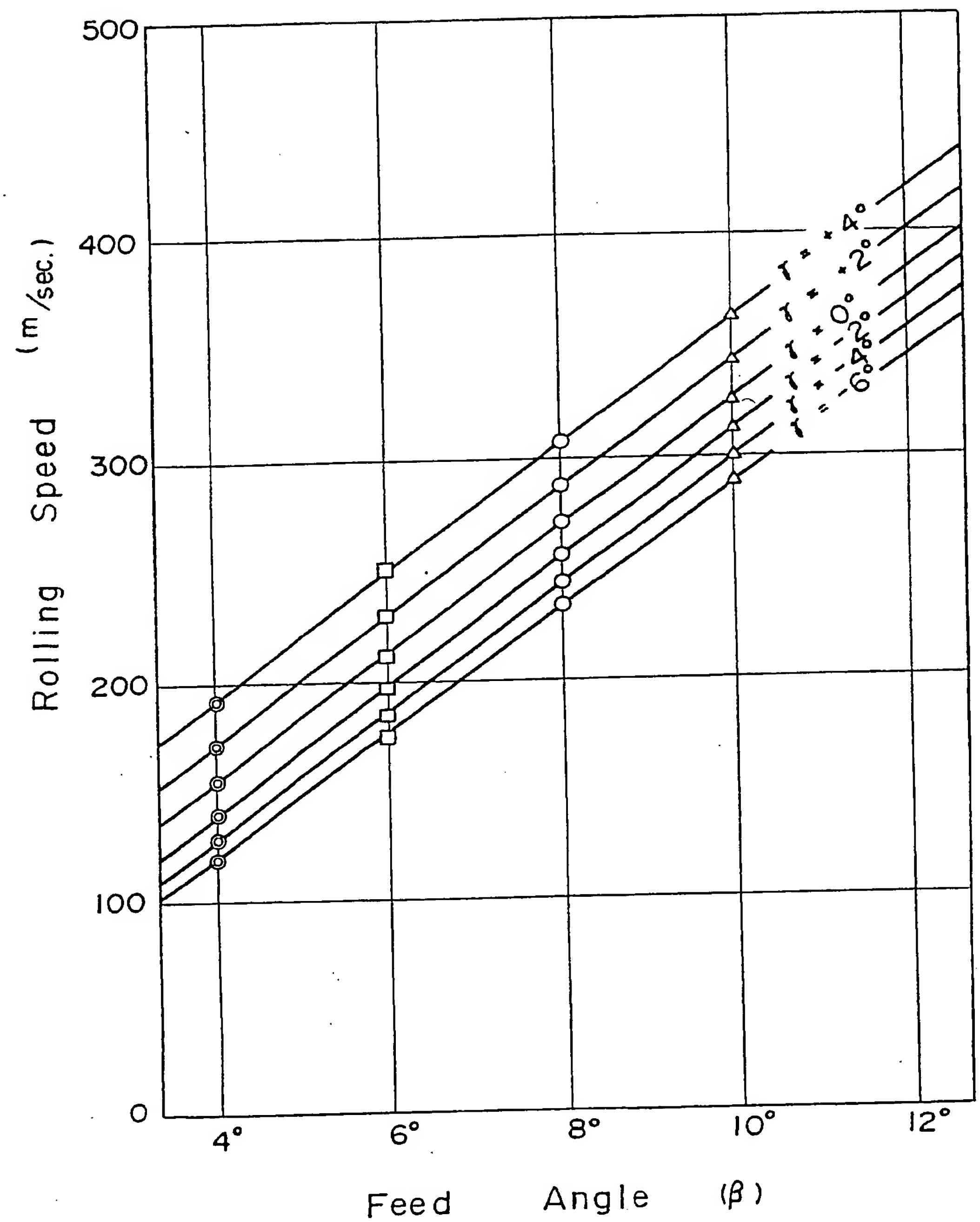

500
400
300
200
100
0
4°
6°
8°
10°
12°
Rolling Speed (m/sec.)
Feed Angle (β)
γ = +4°
γ = +2°
γ = 0°
γ = -2°
γ = -4°
γ = -6°

FIG. 14

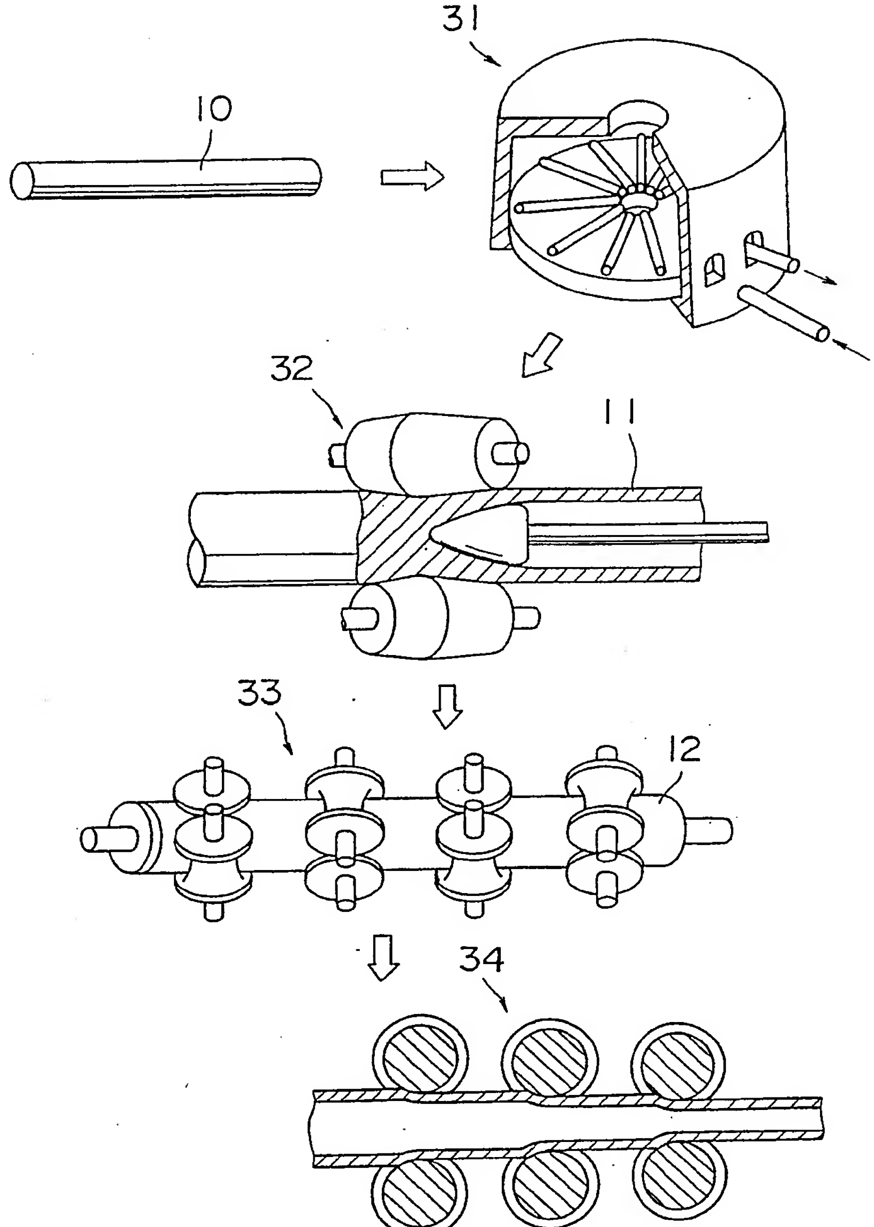
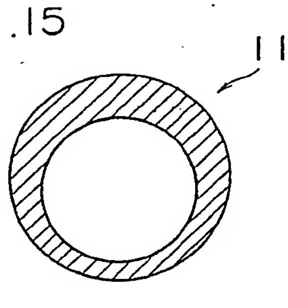


FIG. 15



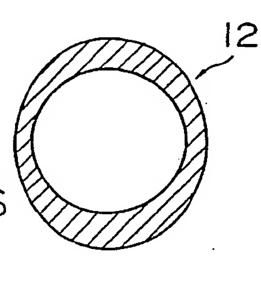


FIG. 16

FIG. 17

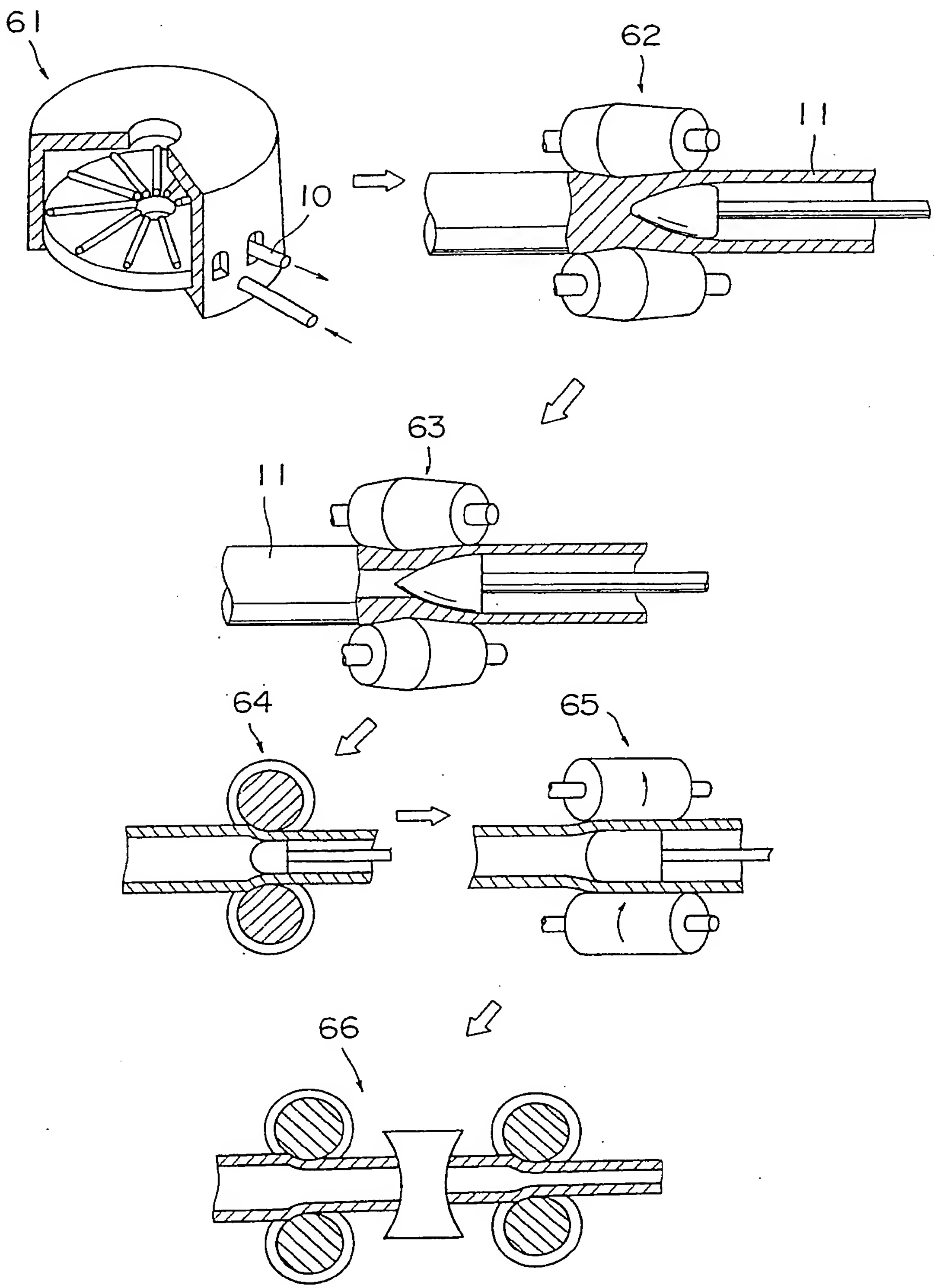
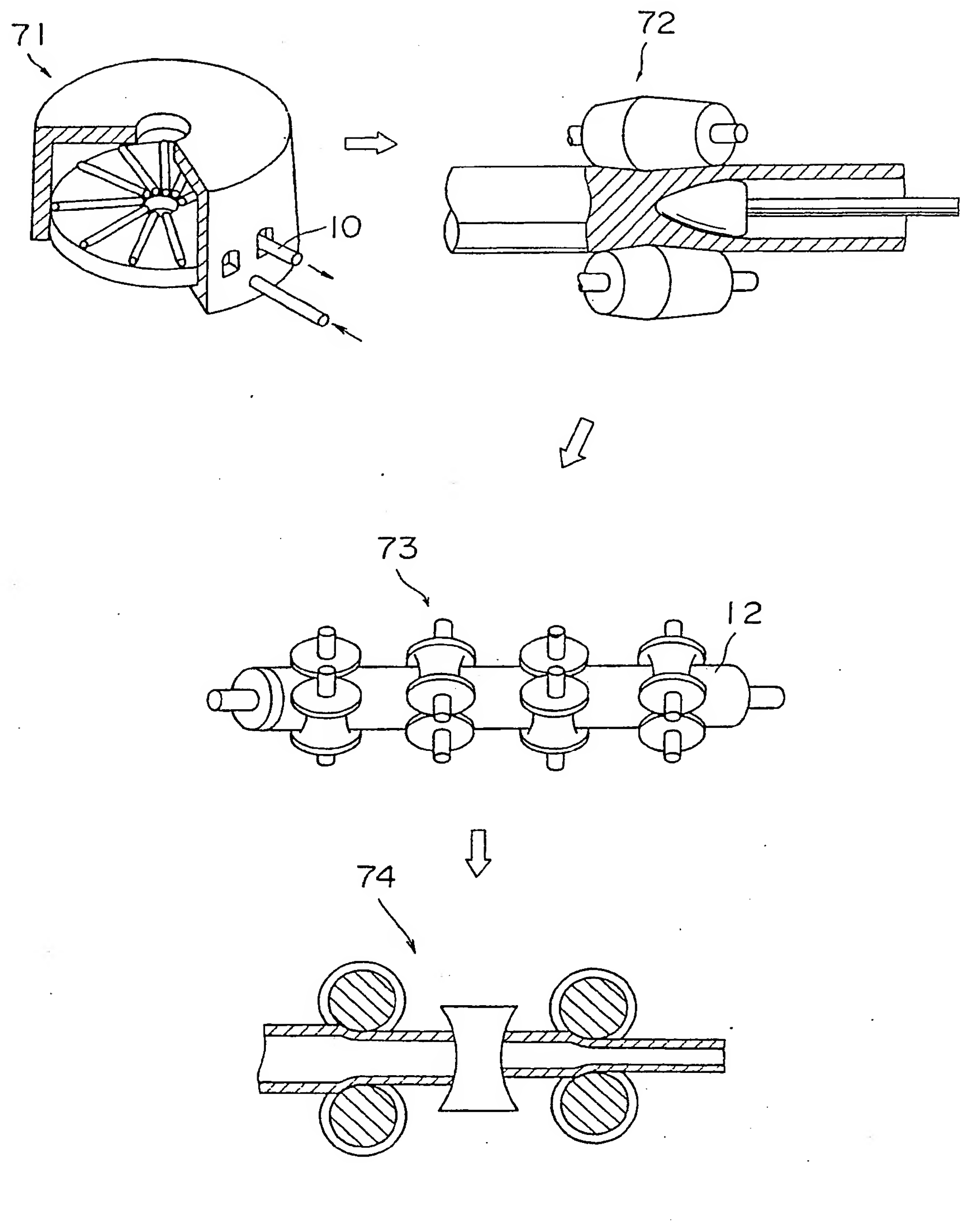


FIG.18



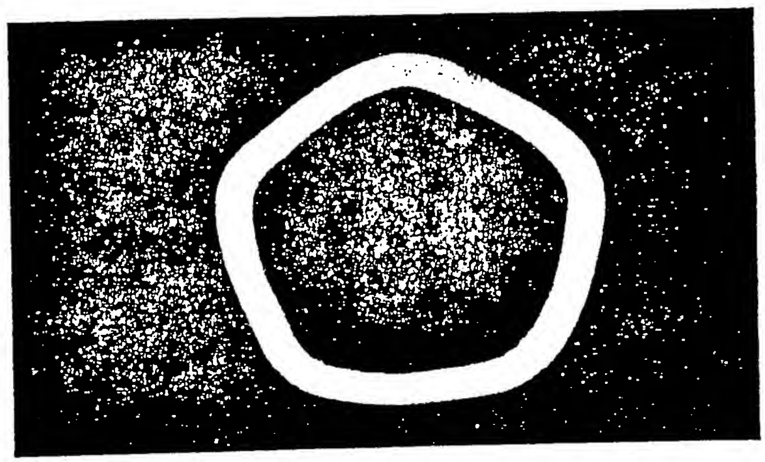


Fig. 19

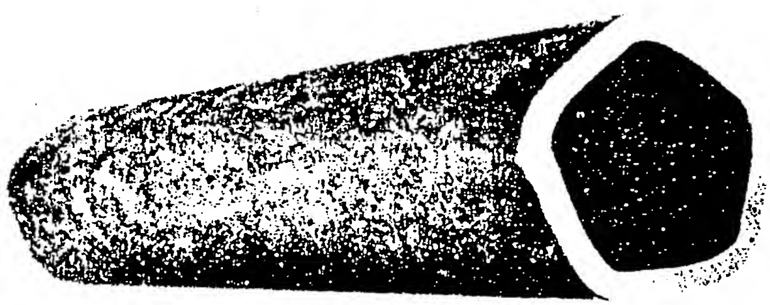


Fig. 20

SPECIFICATION
Process for Manufacturing Seamless Metal Tubes

The present invention relates to a process for manufacturing seamless metal tubes in which hollow shells produced by piercing billets are subjected to wall thickness equalization and/or outside diameter adjustment.

Seamless metal tubes, and more particularly small-diameter tubes, e.g., tubes 1 to 6 in. (0.254 to 1.524 cm) in diameter, often have the problem of wall eccentricity. The problem is explained as follows:

The manufacture of small diameter tubes, 1—6 in. (0.254 to 1.524 cm) in diameter, is conventionally carried out in manner as illustrated in fig. 14 of the accompanying drawings. That is, round bar stock or round billet 10 is heated to 1200—1250°C in a rotary hearth furnace 31, is pierced by means of a piercing mill 32 (e.g. Mannesmann piercer), and the resulting hollow shell 11 is processed by a continuous elongating mill 33 (e.g. a mandrel mill) into a semi-finished pipe 12 having a wall thickness substantially comparable to that of a finished tube. The semi-finished tube 12 is then heated in a reheating furnace (not shown) and dimensioned by means of a stretch reducer 34 to the specified outside diameter. In conjunction with outside diameter dimensioning, some wall-thickness adjustment is made to obtain the required thickness of finished tube. Described above is a typical process for manufacture of small diameter tubes on a mass-production line known as Mannesmann mandrel mill line. A study of wall eccentricity occurrences under this process revealed that eccentric wall eccentricity in which, as Fig. 15 illustrates, the inside and outside diametral centres do not agree with each other was found with hollow shells 11 from the piercer 32, the wall eccentricity ratio ranging from 5% to 15%. With semi-finished tubes 12 from the elongating mill 33, symmetrical wall eccentricity in which, as Fig. 16 illustrates, the inside and outside diametral centres are identical was found to have occurred in the range of 3 to 5% in terms of wall eccentricity ratio, this eccentricity being added to the above eccentric wall eccentricity. The term "wall eccentricity ratio" referred to herein is defined as [(Tmax—Tmin)/Tmean]x100%, wherein Tmax is the maximum wall thickness of tube section, Tmin is the minimum wall thickness thereof, and Tmean is the mean wall thickness thereof.

No appreciable change was caused at the stretch reducer 34. In effect, the wall eccentricity caused at the piercer 32 was introduced into the finished product substantially as it was. It was also discovered that the continuous elongating mill was ineffective for the purpose of wall thickness equalization and that, especially where rolling reduction was not uniform in successive passes, some symmetrical wall eccentricity was added to the initially caused eccentricity.

In such Mannesmann mandrel mill process there is sometimes provided a shell sizer between the piercer 32 and the continuous elongating mill 33. A shell sizer comprises 5 to 7 stands of two-roll or three-roll type, each having a grooved roll, arranged in tandem. Each hollow shell 11 is passed through the shell sizer in the axial direction without rotation, so that its outside diameter is reduced to the required outside diameter. It was primarily for the purpose of decreasing the number of sizes of billets to be provided to meet the specifications of various different finished products that the shell sizer was introduced into the Mannesmann mandrel mill process. Granting that only one size of hollow shell is obtainable from one particular size of billet at the piercer 32, the provision of a shell sizer makes it possible to obtain a plurality of shell sizes. It follows that the shell sizer permits simplification of billet dimensions and further, continuous casting of billets. Even if such a sizer is applied, however, the wall eccentricity caused in the earlier stage can hardly be corrected: only slight thickness change takes place adjacent the roll flanges, and there is little metal flow in the peripheral direction of the shell.

In the manufacture of medium-diameter tubes, 6 to 16 inches (1.524 to 4.064 cm) in diameter, a process known as Mannesmann plug mill process is often used which, as Fig. 17 illustrates, comprises a billet 10 heated in a heating furnace 61 being pierced by a piercer 62 into a hollow shell 11, the shell being passed through a rotary elongator 63 for inside diameter expansion or wall thickness reduction, the resulting product being delivered as such to a plug mill 64, then passed through a reeler 65 and a sizer 66 to provide a finished product. The rotary elongator 63 is such that a plug is inserted into the hollow shell 11 to perform wall thickness reduction in cooperation with opposed rolls arranged in oblique relation to the shell, so that wall thickness reduction of the hollow shell is performed with outer and inner tools under controlled conditions permitting positive metal flow in the peripheral direction for the correction of any wall eccentricity caused at the earlier stage. Insofar as the plug mill process is concerned, there is not much problem of wall eccentricity with medium diameter tubes as is the case with Mannesman mandrel process in the manufacture of small diameter tubes. Recently, however, there has been a growing tendency for a continuous type elongator called "Multi-stand pipe mill", featuring high reduction capacity and high efficiency, to be used in the manufacture of medium diameter tubes. Where such a mill is combined with above mentioned piercer, the manufacturing line consists of a heating furnace 71, a piercer 72, a multi-stand pipe mill 73 and a sizer 74, as illustrated in Fig. 18. With such a simplified arrangement, one similar to that for small-diameter tube manufacturing, a problem similar that noted with regard to small diameter tubes is involved: that any wall eccentricity such as that caused at the piercer 72 is carried into the finished product. This difficultry may be overcome by providing a rotary elongator between the piercer and the multi-stand pipe mill 73. Indeed,

such an arrangement is adopted in a known process wherein square bloom is used as the stock and wherein a press piercing mill is used in place of an ordinary type of piercer. This arrangement, however, has an economic disadvantage in that two different elongators are used, that is, a rotary elongator and multistand pipe mill, which fact is unfavourable from the standpoint of equipment investment efficiency.

An object of the present invention to provide a process for manufacturing seamless metal tubes by using a continuous elongating mill such as mandrel mill or multi-stand pipe mill, or a single-stand type elongator such as plug mill or assel mill, wherein a significant decrease in wall eccentricity ratio can be achieved.

It is another object of the invention to provide a process for manufacturing seamless metal tubes which permits the number of sizes of billets to be prepared as stock for tube manufacturing to be decreased and which can be developed into an integrated tube manufacturing line so that continuously cast billets can be put directly into the process for tube making.

It is a further object of the invention to provide a process for manufacturing seamless metal tubes which permits effective correction of wall eccentricity or equalization of wall thickness even if the ratio of wall thickness to outside diameter (t/D) is as small as 5—15%.

It is a still further object of the invention to provide a process for manufacturing seamless metal tubes wherein hollow shells, whether from a Mannesmann piercer or from a press piercer, can be corrected as to their wall eccentricity, thereby ensuring a higher quality of the resulting finished tubes.

According to the present invention there is provided a process for manufacturing seamless metal tubes comprising the step of subjecting a shell being worked to outside-diameter reduction by means of a rotary mill having two or four rolls arranged around a pass line and without using internal sizing tools.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 is a diagrammatic illustration of the sequence of stages in a process according to an embodiment of the invention;

Fig. 2 is an explanatory view showing the inclined disposition of rolls;

Fig. 3 is a diagrammatic illustration of the sequence of stages of another embodiment of the process of the invention;

Figs. 4(a) and 4(b) are graphs illustrating the effect of the present invention;

Figs. 5(a) and 5(b) are graphical representations showing the effect of a process similar to that of the invention but applied to a two-roll type rotary mill;

Fig. 6 is an diagrammatic illustration showing a sequence of stages of a still further embodiment of the process of the invention;

Fig. 7(a), 7(b) and 7(c) are views illustrating a roll arrangement in a wall-thickness equalizer having a positive cross angle (toe angle);

Figs. 8(a), 8(b) and 8(c) are views showing the roll arrangement in a wall-thickness equalizer having a negative cross angle;

Figs. 9 to 11, inclusive, are charts showing pentagon deformation data based on experiments with the process of the invention;

Figs. 12 and 13 are graphs showing observations based on experiments with the process of the invention;

Fig. 14 is an illustration showing the sequence of manufacturing stages in a conventional Mannesmann mandrel mill process;

Fig. 15 is an explanatory view showing an eccentric wall eccentricity;

Fig. 16 is an explanatory view showing a symmetrical wall eccentricity;

Fig. 17 is an illustration showing the sequence of manufacturing stages in conventional Mannesmann plug mill process;

Fig. 18 is an illustration showing a tube manufacturing line employing a multi-stand pipe mill; and

Figs. 19 and 20 are photographic representations showing a pentagon-shaped angular deformation seen in a seamless steel tube.

A basic application of the process of the present invention to the Mannesmann mandrel process will be explained first. According to one basic aspect of the invention, the process includes a stage in which a rolling operation is carried out by means of a three-roll or four-roll type rotary mill to reduce the outside diameter of the hollow shell without any internal sizing tool being used. The purpose of this stage is primarily to correct wall eccentricity or equalize wall thickness. Generally, the stage precedes the operation of above said elongating mill whose main function is wall thickness reduction.

The process of wall eccentricity correction by the rotary mill is such that shells are rolled as they are fed while being rotated, whereby positive metal flow in the peripheral direction takes place despite the absence of internal sizing tools.

Fig. 1 shows the sequence of stages in a process according to an embodiment of the present invention, used in the manufacture of small diameter tubes. A round billet 10 is heated to 1200—1250°C in a rotary hearth type heating furnace 1, then pierced by a piercer 2 into a hollow shell 11. The hollow shell is then passed through a three-roll type rotary mill 3 (hereinafter referred to as "wall-

thickness equalizer") which has no internal sizing tool, such as a plug, mandrel bar or the like. The wall-thickness equalizer 3, as stated above, has no internal sizing tool; its primary object is to reduce the outside diameter of the hollow shell 11 so as to correct wall eccentricity. Essentially it is a rolling mill having three rolls of truncated cone or barrel shape arranged in oblique relation to the axis of the hollow shell. In configuration, it is similar to a three-roll type piercer or assel mill from which the plug or mandrel bar, as the case may be, has been removed.

The expression "arranged in oblique relation" as used herein means that the rolls are arranged in such a way that their respective axes are inclined at an equal angle relative to the condition of their being parallel to the axis of the hollow shell and in a tangential direction to an imaginary circle (shown by an alternate long and two-short-dashes line in Fig. 2) centered at the axis of the shell, all the roll axes being in the same direction. The inclined roll arrangement is shown in a direction perpendicular to the direction of shell feed in Fig. 1, and in the direction of shell feed in Fig. 2. The angle at which each roll is inclined is hereinafter referred to as "feed angle".

The wall thickness equalizer 3 performs 5—50% diameter reduction. Correction of the wall eccentricity takes place in the course of the diameter reduction operation. The shell 11′ from the equalizer 3 is then fed to the mandrel mill 4 where it is subjected to wall thickness reduction to produce a semi-finished tube 12 having a wall thickness almost comparable with that of a finished tube. After heating in a reheating furnace (not shown), the semi-finished tube 12 is passed through a reducing mill 5 for dimensioning to a finished size.

Fig. 3 illustrates the stage sequence in another embodiment of the process of the invention, used in the manufacture of medium diameter tubes. The stages up to that of wall eccentricity correction, namely, heating furnace 1, piercing mill 2 and wall-thickness equalizer 3, are same as those described in the case of small-diameter tube making in relation to Fig. 1. A hollow shell 11′ from the equalizer 3 is fed to a multi-stand pipe mill 6 for working into a semi-finished tube 12 having a wall thickness almost equal to that of a finished tube. After heating in a reheating furnace (not shown), the semi-finished tube 12 is passed through a sizer 7 in which it is worked to the specified size. The two embodiments described above, both employ a continuous type of elongator such as a mandrel mill or multi-stand pipe mill, as the case may be. This invention, however, may equally well be applied to a tube making line employing a single-stand elongator such as, for example, a plug mill. For this purpose, the line may comprise a rotary piercer, a wall-thickness equalizer, a rotary elongator, a plug mill, a reeler, and a sizer; or a press piercing mill, a wall-thickness equalizer, a rotary elongator, a plug mill, a reeler, and a sizer.

Next, the effect of the process according to the invention will be explained on the basis of specific examples. Figs. 4(*a*) and 4(*b*) are graphs showing observation data of the wall eccentricity correcting effect of a three-roll type wall-thickness equalizer in accordance with an embodiment of the invention. Figs. 5(*a*) and 5(*b*) are graphs showing data of a similar nature observed with a two-roll type rotary mill for comparison purposes. The data presented in Figs. 4(*a*) and 4(*b*) relate to the results observed with a three-roll type equalizer having a feed angle of 6°, whereas the data in Figs. 5(*a*) and 5(*b*) relate to the results observed with a two-roll type rotary mill having a feed angle of 8°. In the graphs, the outside-diameter reduction ratio is given on the abscissa, and the correction ratio of wall eccentricity

$$\left(\frac{\text{max. thickness—min. thickness}}{\text{mean thickness}} \times 100\%\right)$$

on the ordinate. The wall eccentricity ratio with respect to each hollow shell 11′ prior to being fed to the equalizer or rotary mill, as the case may be, is used as a parameter.

In Figs. 4(*a*) and 5(*a*), data given relate to results with respect to shells wherein t/D (wall thickness/outside diameter) is 20%, and data in Figs. 4(*b*) and 5(*b*) relate to results with respect to shells, t/D 10%. It is apparent from these graphs that the three-roll type of wall thickness equalizer and two-roll type of rotary mill, both have positive effects in improving wall eccentricity. Furthermore, it is clear that the greater the outside-diameter reduction ratio, the more significant is the effect of correction of wall eccentricity; similarly, the greater the shell wall eccentricity and the higher the wall thickness to diameter ratio (t/D), the more remarkable is the effect of correction of wall eccentricity. It is also noted that the three-roll wall-thickness equalizer according to the invention is more effective than the two-roll rotary mill. Where the latter mill is used, its effect in correcting the wall eccentricity ratio is relatively small if t/D is 10%; and no significant effect is obtainable unless the outside-diameter reduction ratio is increased up to 50% or so. However, increasing the outside-diameter reduction ratio to 50% is undesirable in many ways: smooth roll contact relative to the shell may be hindered; wrinkles may tend to develop in the shell interior; the billet diameter is required to be about double the diameter of the shell at the outlet end of the rotary mill, which fact would make it difficult to provide a heating furnace of a suitable design, particularly in view of a substantially heavier load on the hearth; and not economical. From a practical point of view, therefore, it is not advisable to apply a two-roll type of rotary mill as a wall-thickness equalizer.

Table 1 presents comparative data on billet diameter, tube outside diameter, and wall thickness

at various stages in the process of the invention and at those in conventional Mannesmann mandrel mill process.

Table 1

Process	*Billet (mm)*	*Piercer (mm)*	*Wall Thickness equalizer (mm)*	*Mandrel mill (mm)*
Present invention	205ϕ	205ϕx42.5t	186ϕx45.2t	158ϕx30t
Conventional	186ϕ	186ϕx42.5t	—	158ϕx30t

Fifty tube samples were taken from the mandrel mill stage in each process and examined as to their wall-eccentricity ratio. Whereas the eccentricity ratio was 12% with tubes manufactured under the conventional process, tubes from a process according to the present invention showed considerable improvement, with an eccentricity ratio of only 5%.

As can readily be seen from this comparison, the concept of the present invention, when applied to the Mannesmann process, permits a significant decrease in shell wall eccentricity in the course of seamless metal tube making. This means less section deviation in the finished tube and better-quality seamless metal tubes. Moreover, as compared with the rotary elongator, the wall-thickness equalizer is simpler in construction, costs less, and requires less space. The process of the invention has an added advantage in that the outside-diameter reduction is carried out concurrently with wall eccentricity correction, which fact makes it possible to decrease the number of billet diameter sizes to be supplied to meet various different specifications and thus to establish suitable production lines for continuous billet casting.

Now, the inventors found some new problems when they were experimenting on the process of the present invention to ascertain its effects under various conditions. One problem is that, as may be seen from the comparison of Fig. 4(*a*) with Fig. 4(*b*), where t/D is rather small (e.g. 5—15%), the extent of wall eccentricity correction achievable is fairly small, if the outside-diameter reduction ratio is small. Another problem is that at the end of the reduced shells a so-called pentagon formation is often produced on its outside diameter deforming the section configuration into a pentagon shape, as shown in Figs. 19 and 20. The smaller the t/D, the more noticeable the phenomenon is. This means that it is impossible to compensate insufficient correction of wall eccentricity in the case of the t/D ratio being small by increasing the outside-diameter reduction ratio. What is worse, as the rolling speed becomes higher, pentagon formation extends over a greater length, and therefore, incorporating a wall thickness equalizing mill into the manufacturing line may lead to a lowering of the production efficiency. Thus, it became apparent that overcoming such a deformation difficulty is of extreme importance in order that the scope of application of the invention may be extended even to cases where the t/D ratio is small and if the invention can be put into practice effectively and without lowering production efficiency.

The inventors discovered that the difficulty could be overcome by employing a cross-type rotary mill. Accordingly, a more practical embodiment of the invention comprises the step of subjecting shells being worked to outside-diameter reduction by means of a cross roll-type rotary mill (or a cross-type rotary mill) having three or four rolls arranged around a pass line, the axes of the rolls being inclinable so that the shaft ends on either side of the rolls may stay close to or stay away from the pass line and so that the shaft ends may face in the peripheral direction on one and the same side of the shell being worked, and without employing internal sizing tools.

An embodiment of the process of the invention using a cross roll-type rotary mill having three-rolls is explained below. In Fig. 6 an embodiment in which a cross roll-type rotary mill is used in a Mannesmann plug mill line is shown.

A round billet 10 is heated to 1200—1250°C, for example, in a heating furnace 1 of rotary hearth type. The billet 10 is then pierced by a piercing mill 2 (Mannesmann piercer) into a hollow shell 11, which is then passed through a cross roll-type of rotary mill 3 (hereinafter referred to as "wall-thickness equalizer") which is not provided with any internal sizing tool such as a plug or Mandrel bar. The wall-thickness equalizer 3, designed for correcting the wall eccentricity of the hollow shell 11, is essentially a rotary mill having 3 rolls 31 (only two rolls shown in Fig. 6) of a circular truncated cone type, each having a ridge portion located about half way along in the direction of its axis, which has no internal sizing tool, as above mentioned. The rolls may be of barrel shaped instead of truncated cones.

The hollow shell 11 is subjected, at the thickness equalizer 3, to outside-diameter reduction, during which operation it concurrently has its wall eccentricity corrected, and the so worked shell 11′ is then fed to a plug mill 8, where it is subjected to elongation for wall thickness reduction, whereby it is made into a semi-finished tube 12 having a wall thickness substantially comparable with that of a finished tube. After being subjected to reeling by means of a reeler 9, the semi-finished tube 9 is passed through a sizer 7 in which it is dimensioned to its finished size.

Some specific aspects of the configuration of the wall-thickness equalizer are shown in Figs. 7(a), 7(b) and 7(c). Fig. 7(a) is a front elevation showing relative positions of rolls 31 which constitute a rolling mill as wall-thickness equalizer 3, as seen from the inlet side of the mill. Fig. 7(b) is a sectional view taken along the lines I—I in Fig. 7(a). Fig. 7(c) is a side view taken on the line II—II in Fig. 7(a). Each roll 31 has a ridge portion 31*a* about half way along in the axial direction. The ridge 31*a* forms the boundary between the front portion (inlet side) and the rear portion (outlet side) of each roll. The front portion is gradually reduced in diameter toward the front shaft end, and the rear portion is gradually enlarged in diameter toward the rear shaft end. Thus, the roll is shaped like a circular truncated cone, and has an inlet surface 31*b* and an outlet surface 31*c*. The rolls 31 are arranged around a pass line X—X for shell 11 (pass line X—X corresponds to shell axis) in such a way that their centres, each represented by an intersection point O between an axis line Y—Y and a plane including the ridge 31*a* (said intersection point to be hereinafter referred to as the roll centre), are positioned at an equal spacing on a plane crossing at right angles with the pass line X—X, with their respective inlet surface 31*b* side portions disposed on the inlet side in the direction of flow of shells 11. The axes Y—Y of the rolls 31, as seen from Fig. 7(*b*), are inclined at an angle γ (hereinafter referred to as the cross angle) relative to the pass line X—X so that their shaft ends on the same side, as viewed on a plane, that is, the front-side (inlet side) shaft ends approach the pass line X—X. The inclined arrangement of the rolls 31 is in the same manner as that shown in Figs. 1 and 2. That is, the front ends of the shafts face the peripheral direction on one and the same side (clockwise) of shell 11 as shown in side elevation in Fig. 7(*a*), being inclined at a feed angle β, as shown in Fig. 7(*c*). The rolls 31 are connected to a drive source not shown, and are driven to rotate in same direction. Shell 11 fed between the rolls 31 is moved in the axial direction while being rotated about the axial line. In other words, shell 11 is subjected to outside-diameter reduction while being screwed forwards, whereby its wall eccentricity is corrected.

Fig. 8 shows another example of a wall-thickness equalizer 3. In Fig. 8(*a*) it is illustrated in front elevation, as seen from the inlet side of the mill. Fig. 8(*b*) is a section taken along the lines III—III in Fig. 8(*a*). Fig 8 (*c*) is a side view taken on the line IV—IV in Fig. 8(*a*). In the wall-thickness equalizer 3 shown, rolls 41 each have a ridge 41*a* located approximately centrally, in the axial direction. Each roll 41 consists of a front and rear portion, with the ridge 41*a* located between. The front portion gradually increases in diameter towards the front end of the shaft, and the rear portion is gradually reduced in diameter towards the rear end of the shaft. Each roll 41 is shaped like a circular truncated cone and has an inlet surface 41*b* and an outlet surface 41*c*. The rolls 41 are so arranged that the inlet surface (41*b*) side is positioned on the up-stream side of flow of shells 11, with a cross angle set at γ and a feed angle at β. The inclination in the peripheral direction, i.e., feed angle β is set so that the rear end of the shaft is arranged in the clockwise direction. Whereas the cross angle γ for rolls 31 in Figs. 7(*a*)—7(*c*), as can be clearly seen from Fig. 7(*b*), is set in such a way that the inlet surface 31*b* of each roll 31 is relatively close to the pass line X—X for shell 11, the cross angle γ for the rolls 41, shown in Figs. 8(*a*)—8(*c*) and as is clear from Fig. 8(*b*), is in reverse relation to that in Fig. 7(*b*). The angle in the former case is hereinafter referred to as positive angle ($\gamma>0$), and the one in the latter case as negative angle ($\gamma<0$).

Experiments were made on a three-roll cross roll-type rotary mill like the ones shown in Figs. 7(*a*)—(*c*) and 8(*a*)—(*c*), by subjecting shells to outside-diameter reduction, without using internal sizing tools such as, for example, a mandrel or plug. The results of these experiments are explained below.

Truncated-cone-shaped rolls, each 180 mm in barrel length and 200 mm in diameter at the ridge, were used for the rolls in the rotary mill, with the feed angle designed in three different ways and the cross angle in six different ways. Pentagon formation occurrences were examined with respect to various different combinations. Sample shells were used in five varieties in the outside diameter range of 80 mm—100 mm. The diameter reduction ratio was set at 20%, and the roll speed at 200 r.p.m.

The experiment results are presented in Figs. 9, 10 and 11, in which mark O denotes no pentagon formation and ⬠ denotes pentagon-shaped angular deformation occurred.

As can be seen from Figs. 9, 10 and 11, cross angle γ feed angle β combinations in roll arrangement have considerable bearing upon pentagon formation control. For such control purposes, it is found most effective to have: ① feed angle β set relatively small; ② cross angle γ set small in the positive angle range; and ③ cross angle γ set relatively large in absolute terms if given a negative angle value. What is meant by setting the feed angle β relatively small is that the screwing pitch in rolling is small and further that the shell rotation speed in the roll-shell contact zone is increased. Thus, it can be said that a small pitch of shell screwing and a high shell rotational speed are effective for the purpose of post-rolling pentagon formation control.

Setting the positive cross angle γ relatively small or setting the negative cross angle γ relatively large also means that shell screwing pitch is small and that shell rotation speed is increased. From the viewpoint of pentagon formation control, however, it is more effective to change the cross angle γ than to change the feed angle β.

The fact that setting β and γ values relatively small (where $\gamma<0$, setting relatively large) is effective, as such is assumed to be attributable to the following reasons: as a result of these measures, screwing pitch becomes smaller and shell rotation speed is increased. Thus, various portions of the

shell are subjected to the diameter reducing action of the rolls more times. Moreover, time per turn of action becomes short. Consequently, wall thickness is effectively reduced in a smooth flow over the entire area.

Theoretically, the above described feed and cross angle roll setting may be considered as preventive measures against pentagon formation applicable to a two-roll rotary mill having no internal sizing tool and in which the roll axes are inclined relative to the pass line, for the purpose of preventing angular deformation which present substantially triangular configuration as often observed and typically in the case of diameter reducing for shells, t/D 5—15%. Where a two-roll type of rotary mill is used, however, the expected wall eccentricity correction effect is very small; therefore, any effect sufficient to justify the cost of equipment may not be obtained.

Referring to a diameter reduction operation employing a three-roll cross roll-type rotary mill, as above described, as a wall-thickness equalizer, without using internal sizing tools, experiments were made with regard to the relationship between the correction ratio of wall eccentricity and the feed and cross angle settings β and γ for the rolls. Results of the experiments are explained below. For the purpose of the cross roll-type rotary mill, rolls of the same specifications as used in the earlier mentioned experiments were used. The sample shells used were of the following descriptions; t/D 10%, five sizes within an outer diameter range of 80 mm—100 mm; wall eccentricity ratios 10%, 20%, and 30%. The samples were subjected to rolling at rotational speed of 200 r.p.m. The results are shown graphically in Fig. 12, in which the abscissa denotes feed angle β and the ordinate denotes the correction ratio of wall eccentricity (%).

Correction ratio of wall eccentricity referred to herein is expressed by the following formula:

$$\text{Correction ratio of wall eccentricity} = \frac{\text{Wall eccentricity ratio of shell} - \text{Wall eccentricity ratio of product}}{\text{Wall eccentricity ratio of shell}} \times 100\%$$

As can be clearly ascertained from the graph, in order to improve the correction ratio of wall eccentricity, it is most effective to have: ① the feed angle β set relatively small; ② the cross angle γ set small in the positive angle range; and ③ the cross angle γ set relatively large in absolute terms if given a negative angle value. All this agrees with the data on pentagon formation control based on the experimental results presented in figs. 9, 10 and 11. Wall thickness is gradually transferred in the peripheral direction little by little over many times. That is, thickness transfer from a thick portion to thin portion in the peripheral direction is selectively accomplished, and thus wall eccentricity is corrected.

If the feed angle β is set relatively small, with cross angle γ set, on the negative angle side, relatively large in absolute terms, a correction ratio of wall eccentricity of more than 60% can be obtained This stands in striking contrast with the fact that where a two-roll type rotary mill in which the roll axes are inclined relative to the pass line but do not cross it is employed as a thickness equalizer, the correction ratio obtainable may be at most 20% or so. The fact that a correction ratio as high as 60% is obtainable, means that a shell eccentricity ratio of 30% can be reduced to 12%; that, in the case of a shell with an eccentricity ratio of 20%, the ratio can be reduced to 8%; and if the eccentricity ratio is 10%, it can be reduced to 4%.

Next, where a diameter reduction operation is carried out by means of above described three-roll cross roll-type rotary mill and without employing any internal sizing tools, the relations between rolling speed and feed and cross angle settings β and γ for the rolls will be explained on the basis of experimental data. The rolls used were of the sume dimensions as those mentioned earlier. Sample shells of the following description were used: t/D 10%, outside diameter 90 mm, wall thickness 9.0 mm. The shells were subjected to an outside-diameter reduction under the following conditions: reduction ratio 20%, rotation velocity 200 r.p.m. The results are set out graphically in Fig. 13, in which the abscissa denotes feed angle β and the ordinate denotes rolling speed.

As is clear from the graph, in order to increase rolling speed, it is desirable to have: ① the feed angle β set relatively large; ② the cross angle γ set relatively small in absolute terms, if it is given a negative value; and ③ the cross angle γ, if on the positive side, set relatively large in absolute terms.

It is noted that the above described conditions for increasing rolling speed are in complete disagreement with the earlier mentioned conditions for preventing pentagon formation or for improving the correction ratio of wall eccentricity. This is quite natural since the conditions for the latter purposes are largely related with the matter of reducing the screwing pitch for the shells. If emphasis is placed on metal tube quality only, rolling speed may well be sacrificed. As a matter of practice, however, when incorporating a three-roll cross roll-type rotary mill, as a thickness equalizer, in a manufacturing process for seamless metal tubes, the question of efficiency balance is of great importance, especially where a high-productivity, metal tube making process is used. The presence of a significant unbalance between such a rotary mill and existing rolling mills at adjacent stages, for example, piercer and plug mill, may often make such an introduction impracticable. Therefore, in

setting up a three-roll cross roll-type rotary mill as above described, prudent consideration must be given to productivity as well as to pentagon formation control and wall eccentricity correction so that set-up conditions may be determined from a standpoint of the overall requirements.

Preferred set-up conditions are presented below, by way of example.

i) Basically, roll set-up conditions for a cross roll-type rotary mill should be such that the feed angle β is set as small as feasible, with the cross angle γ set as large as possible in absolute terms on the negative angle side. Decrease in productivity due to the use of a smaller feed angle β may be prevented, preferably by increasing rotation speed of rolls as much as possible.

ii) It is to be noted, however, that an excessive increase in rotation of speed of the rolls may often be a cause of trouble and undesirable from the standpoint of safety, and further that it may more or less, have a negative effect on pentagon formation control and wall eccentricity correction. Therefore, when setting the cross angle on the positive angle side, it is desirable to set the feed angle β at as small a value as is possible and to compensate any decrease in productivity resulting therefrom by setting the cross angle relatively large. It is also desirable when setting the cross angle γ on the negative angle side, to use as large a value in absolute terms as feasible and to compensate for any resultant decrease in productivity by setting the feed angle as large as possible.

iii) If there is no problem with the productivity balance for the thickness equalizer in the tube manufacturing process, it is desirable that the feed angle β is set as small as possible, with cross angle γ set on the negative angle side as large as possible in absolute terms, whereby a greater pentagon formation control and correction effect for the wall eccentricity may be obtained.

The process described above is not only applicable to Mannesmann mandrel line, but also the correction of spiral wall eccentricity produced in the Mannesmann mandrel mill, Mannesmann multi-stand pipe mill, Mannesmann assel mill and Mannesmann pilger mill lines and/or for the purpose of correcting parallel eccentricity developed in Ugine-Sejournet extrusion and Ehrhardt push bench reducing lines. Naturally, it is applicable to a tube manufacturing line employing a press piercer instead of Mannesmann piercer.

For the purpose of applying the process of the present invention to the various lines referred to above, the following layouts are recommended.

(1) In Mannesmann mandrel mill line (heating furnace→Mannesmann piercer→mandrel mill→reheating furnace→stretch reducer), a wall-thickness equalizer is provided preferably on the outlet side of the Mannesmann piercer or, depending upon conditions, on the outlet side of mandrel mill for correcting wall eccentricity. In this case, wall eccentricity correction or wall thickness equalization may be effected with shells in a thin wall range such as t/D 5—15%.

(2) In the Mannesmann plug mill line (heating furnace→Mannesmann piercer→rotary elongator→plug mill→reeler→sizer), the wall eccentricity correction or wall thickness equalization operation is desirably carried out on the outlet side of the Mannesmann piercer or, depending upon conditions, on the outlet side of the plug mill. In a case in which the piercing ratio at the Mannesmann piercer is substantially large, the rotary elongator may be omitted.

(3) In the Mannesmann multi-stand pipe mill line (heating furnace→Mannesmann piercer→rotary elongator→multi-stand pipe mill→reheating furnace→sizer), the wall eccentricity correction or wall thickness equalization operation is carried out desirably on the outlet side of piercer or of the rotary elongator or depending upon conditions, on the outlet side of the multi-stand pipe mill.

(4) In the Mannesmann assel mill line (heating furnace→Mannesmann piercer→assel mill→reheating furnace→sizer→rotary sizer), eccentricity correction or wall thickness equalization is preferably carried out on the outlet side of the Mannesmann piercer or, depending upon conditions, on the outlet side of the assel mill. Where the piercing ratio at the Mannesmann piercer is substantially large, the assel mill may be omitted.

(5) In the Mannesmann pilger mill line (heating furnace→Mannesmann piercer→pilger mill→sizer), eccentricity correction or wall thickness equalization is carried out preferably on the outlet side of Mannesmann piercer or, depending upon conditions, on the outlet side of pilger mill.

(6) In the Ugine-Sejournet extrusion line (heating furnace vertical press horizontal press), the wall eccentricity correction or wall thickness equalization operation is preferably carried out on the outlet side of the vertical press, but depending upon conditions, such operation may be carried out on the outlet side of the horizontal press.

(7) In the Ehrhardt push bench reducing line (heating furnace Ehrhardt vertical press push bench), wall eccentricity correction or wall thickness equalization is preferably carried out on the outlet side of the Ehrhardt vertical press, but may be carried out on the outlet side of the bench depending upon conditions.

It is noted that the above described examples relate to cases where a three-roll cross roll-type rotary mill is employed as a thickness equalizer. However, the process of the present invention is also applicable where a four-roll cross roll-type rotary mill is used. In this case, a greater correction effect may be obtained. This can be readily anticipated from the fact that the rolling pressure is distributed over four rolls. According to the inventors' estimation, where β is on the negative angle side and γ is relatively small, a correction ratio of wall eccentricity of 90% or more may be attained. From the viewpoint of construction, a four-roll cross roll-type rotary mill can be obtained only be increasing the

number of rolls arranged around the pass line from above said three to four. However, four rolls make the arrangement complicated, and therefore, it is desirable that two of the four rolls employed as drive rolls and the other two as idling rolls.

As described above, the embodiment of the process of the invention employs a three-roll or four-roll cross-type rotary mill as a wall-thickness equalizer; and by subjecting shells to wall-diameter reduction and without using internal sizing tools such as, mandrel bar and plug, an extremely good correction effect can be obtained without any deformation, such as pentagon formation, being caused to the shells, and without the rolling speed being sacrificed. In addition, by effecting wall eccentricity correction with respect to the shells, section deviation of the finished product can be notably decreased, which means improved product quality. Further, as an important effect of diameter reduction, the number of sizes of billets as the tube making material can be reduced.

Claims

1. A process for manufacturing seamless metal tubes comprising the step of subjecting a shell being worked to outside-diameter reduction by means of a rotary mill having two or four rolls arranged around a pass line and without using internal sizing tools.

2. A process for manufacturing seamless metal tubes according to claim 1, wherein the axes of the rolls are inclined or inclinable so that the shaft ends on either side of the rolls stay close to or stay away from the pass line, said axes being inclined so that the shaft ends on the respective sides of the rolls face in the peripheral direction on one and the same side of the shell being worked.

3. A process for manufacturing seamless metal tubes according to claim 2, wherein said rotary mill is operated in such a way that said roll axes are inclined so that the shaft ends on the inlet side of the rolls stay close to the pass line.

4. A process for manufacturing seamless metal tubes according to claim 2, wherein said rotary mill is operated in such a way that said roll axes are inclined so that the shaft ends on the inlet side of the rolls stay away from the pass line.

5. A process according to claim 1, wherein the axes of the rolls are inclinable so that the shaft ends on either side of the rolls stay close to or stay away from the pass line, said rotary mill being operated without such inclination.

6. A process according to any one of claims 1 to 5, wherein said outside-diameter reduction is carried out in a Mannesmann mandrel mill line including a Mannesmann piercer and a mandrel mill.

7. A process according to claim 6, wherein said outside diameter reduction is carried out between the step of piercing by the Mannesmann piercer and the step of elongating by the mandrel mill.

8. A process for manufacturing seamless metal tubes according to claim 6, wherein said outside-diameter reduction is carried out in said Mannesmann mandrel mill line, after the step of elongation by the mandrel mill.

9. A process according to any one of claims 1 to 5, wherein said outside-diameter reduction is carried out in a Mannesmann plug mill line including a Mannesmann piercer, a rotary elongator and a plug mill.

10. A process according to claim 9, wherein said outside diameter reduction is carried out between the step of piercing by the Mannesmann piercer and the step of rotary elongation by the rotary elongator.

11. A process according to claim 9, wherein said outside diameter reduction is carried out between the step of rotary elongation by the rotary elongator and elongation by the plug mill.

12. A process according to claim 9, wherein said outside-diameter reduction is carried out in said Mannesmann plug mill line, after the step of elongation by the plug mill.

13. A process according to any one of claims 1 to 5, wherein said outside-diameter reduction is carried out in a Mannesmann multi-stand pipe mill line including a Mannesmann piercer, a rotary elongator, and a multi-stand pipe mill.

14. A process according to claim 13, wherein said outside diameter reduction is carried out between the step of piercing by the Mannesmann piercer and the step of rotary elongation by the rotary elongator.

15. A process according to claim 13, wherein said outside diameter reduction is carried out between the step of rotary elongation by the rotary elongator and the step of elongation by the multi-stand pipe mill.

16. A process according to claim 13, wherein said outside-diameter reduction is carried out in said Mannesmann multi-stand pipe mill line, after the step of elongation by said multi-stand pipe mill.

17. A process according to any one of claims 1 to 5, wherein said outside-diameter reduction is carried out in a Mannesmann assel mill line including a Mannesmann piercer and an assel mill.

18. A process according to claim 17, wherein said outside diameter reduction is carried out between the step of piercing by the Mannesmann piercer and the step of elongation by the assel mill.

19. A process according to claim 17, wherein said outside-diameter reduction is carried out in said Mannesmann assel mill line, after the step of elongating by the assel mill.

20. A process according to any one of claims 1 to 5, wherein said outside-diameter reduction is carried out in a Mannesmann pilger mill line including a Mannesmann piercer and a pilger mill.

21. A process according to claim 20, wherein said outside diameter reduction is carried out between the step of piercing by the Mannesmann piercer and the step of elongation by the pilger mill.

22. A process according to claim 20, wherein said outside-diameter reduction is carried out in said Mannesmann pilger mill line, after the step of elongation by the pilger mill.

23. A process according to any one of claims 1 to 5, wherein said outside-diameter reduction is carried out in a Ugine Sejournet extrusion process, before or after the step of extrusion by a horizontal press.

24. A process according to any one of claims 1 to 5, wherein said outside-diameter reduction is carried out in an Ehrhardt push bench reducing line, before or after the step of elongation by a push bench.

25. A process for manufacturing seamless metal tubes substantially as herein described with reference to Fig. 1, 3 or 6 with or without reference to Figs. 2, 4(a) and (b), 7(a) to (c), 8(a) to (c) and 9 to 18 of the accompanying drawings.

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